UTILIZATION OF SOLID WASTES GENERATED FROM STEEL PLANT

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Mining Engineering

By

ROHIT KUMAR

111MN0521

Under the guidance of

Prof. B. K. Pal

Department of Mining Engineering

National Institute of Technology

Rourkela-769008

June, 2015

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CERTIFICATE

This is to certify that the thesis entitled "***UTILIZATION OF SOLID WASTES GENERATED FROM STEEL PLANT***" submitted by ***Rohit Kumar (Roll No. 111MN0521)*** in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:-

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My special thanks to the authority of National Institute of Technology, Rourkela for rendering permission to use their most modern and updated library in connection with the literature survey of the Project work am also grateful to all staffs of Mining Department, NIT Rourkela, who have helped me during the course.

Last but not the least; I am grateful to each one of them who helped me directly or indirectly at various stages of my project work and to all my well-wishers and friends who have patiently extended all sorts of help for accomplishing this dissertation.

DATE:-

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CONTENT

ABSTRACT

About 12 million tons of steel slag is produced a year, which is the by-product of iron and steel manufacture, is generated in India and the most of all the slag is reused for the materials, e.g. cement raw material, road base course material and civil engineering material, by effectively utilizing its characteristics such as chemical components and mechanical properties. Most of its purposes of uses are to replace the functions of the newly mined raw materials from nature and promoting the use of steel slag is an effort to contribute to environmental conservation in this regard. On the other hand, due to the changes in social situation, supply-demand structure in the steel slag market is changing and researchers are developing the technologies to create new features of steel slag and to utilize them, especially in the field of Basic Oxygen Furnace (BOF) slag. In this report, the current production and sales status, processing and reusing technologies of BOF steelmaking slag are mentioned. This work provides an overview of the different types of steel slag that are generated and their properties. In recent years, the need for maximum utilization and recycling of bye-products and recovered waste materials for economic and environmental reasons has led to rapid development of slag utilization. In some areas, mostly the iron and steel slags are being used, and zero waste concept are rapidly growing. The characteristics of the steel slag samples considered in this study are discussed in the context of a detailed view of steel slag properties. This study investigates the utilization of slag as alternative cementitious binder. Knowledge of the chemical, mineralogical, and morphological properties of steel slags is essential because their cementitious and mechanical properties, which play a key role in their utilization. As an example, the frictional properties of steel slag are influenced by its morphology and mineralogy. Similarly, the volumetric stability of steel slag is a function of its chemistry and mineralogy. The chemical, mineralogical, and morphological characteristics of steel slag are determined by the processes that generate this material. Therefore, knowledge of the different types of steelmaking and refining operations that produce steel slag as a bye-product is also required. This work provides an overview of steel slag generation and a detailed literature review on the chemical and mineralogical properties of steel slags are carried out. Moreover, the mineralogical and morphological characteristics of steel slag samples generated from two steel plants in India were evaluated through XRD analyses and SEM studies.

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CHAPTER -1

INTRODUCTION

INTRODUCTION

Steel Industry falls in the list of 29 highly polluting industries as categorised by the Ministry of Environment & Forest. Current production of steel slag is around 12 million tonnes per annum. However, with steel production on the rise, slag production is also expected to increase manifold. In contrast with other nations, most slag produced in India, especially steel slag, is discarded, however, this is increasingly becoming a problem due to paucity of land; utilization of slag is in the trial phase Almost all these slag generated in the course of iron/steel manufacture is effectively used in multiple ways, such as a raw material for cement, a road base course material, a civil engineering work, and a raw material for fertilizer. However, the supply–demand structure in the slag market has been rapidly changing in recent years reflecting not only the sluggish demand for domestic public works and construction projects but also social changes (e.g., governmental policies encouraging the use of other recyclable materials and ever-tightening environmental regulations).

Today the management of mineral commodities has valuable waste of various nature at its disposal, which assume paramount importance and need to be dealt with in a judicious& sustainable manner. Waste management involves management of such materials which have apparently no value. But prior to its management, proper characterization of wastes through physical, mineralogical and chemical analysis is very important because, if the composition is not exactly known, the “Eco saving” to be gained by the utilization of rejects can be lost. With the scenario changing, on passage of time and with the technologies getting regularly upgraded, there is need for use of such waste materials continuously being produced in large quantum through conversion of work materials to either by-products or in-process material for recycling.

The present utilization of blast-furnace slags is an urgent environmental and ecological demand. The increase in the annual accumulation of these pollutants has made the situation more demanding and pressing. Blast furnace slag is a non-metallic by-product from iron and steel industry. The generation of blast furnace slag takes place during the conversion of iron ore or scrap iron to steel, along with coke for fuel. Production of one tonne of steel leads to the manufacturing of500–700 kg of slags. The molten slag comprises about20% by mass of iron production. Presence of hazardous elements such as Pb, Cd, Ni and Cr are common in some steel slags. Different forms of Slag products vary according to the method used in cooling the molten slag. These products range from air-cooled blast furnace slag to expanded or foamed slag to palletized slag, to granulated blast furnace slag. The study concentrates on granulated blast furnace slag, which is cooled and solidified by rapid water quenching to a glassy state with little or no crystallization. Many solutions have been proposed for the technical treatment of the blast furnace slag in variable fields and industries such as concrete works, steel corrosion prevention, reduction of alkali silica reactivity, cement industry, road constructions, clay brick production and ceramic field.

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Wastes generated from steel industry

The Steel industry is considered as resource intensive and pollution prone. Production of steel Involves several operations. It starts from naturally occurring raw materials like coal, iron ores &fluxes to produce hot metal in blast furnace, convert hot metal into steel and subsequently to go for rolling of steel into finished product. Several other activities including production of refractory are also performed in varying magnitude inside the steel works. A large quantity of waste is generated as a sequel to such Activities. To make one-tonne of crude steel even with good raw materials and efficient operation, 5 tonnes of air, 2.8 tonnes of raw materials and 2.5 tonnes of water are required. These will produce in addition to 1 tonne of crude steel, 8 tonnes of moist laden gases and 0.5 tonne of solid wastes [Lean, 1990]. However, in SAIL plants, this figure varies from 820-1,200Kg/tonne of crude steel—which is very high [Prothia and Roy, 1993]. In a steel industry, all the three types of waste materials (gaseous, liquid and solid) are generated. The generation of gaseous waste material is the highest but the management of solid waste material is the most intricate.

Over the years, due to technological changes in steel making and strict environmental regulations and legislation, emphasis on raw material quality and emergence of new markets coupled with innovative ideas of waste reduction and rescue have resulted in drastic reduction in the quantity of waste generated in steel works from 1,200 Kg to less than 200 Kg per tonne of crude steel and recycling rates have reached 95-97% in some parts of the world. However, the solid waste generation presently in Indian steel industry is in range of 600-1,200 Kg/tonne of crude steel and recycling rate varies between 40- 70% which lead to higher production costs, lower productivity and further environmental degradation.

Table: 1 Solid wastes at SAIL steel works (kg/ton of crude steel)

	Blast Furnace slag	Blast furnace Sludge	Steel melting Sludge	Flue Dust	Fly Ash
Produced	520	26	250	30	150
Sold/Recycled	190	-	35	12	12
Dumped	330	26	215	18	138

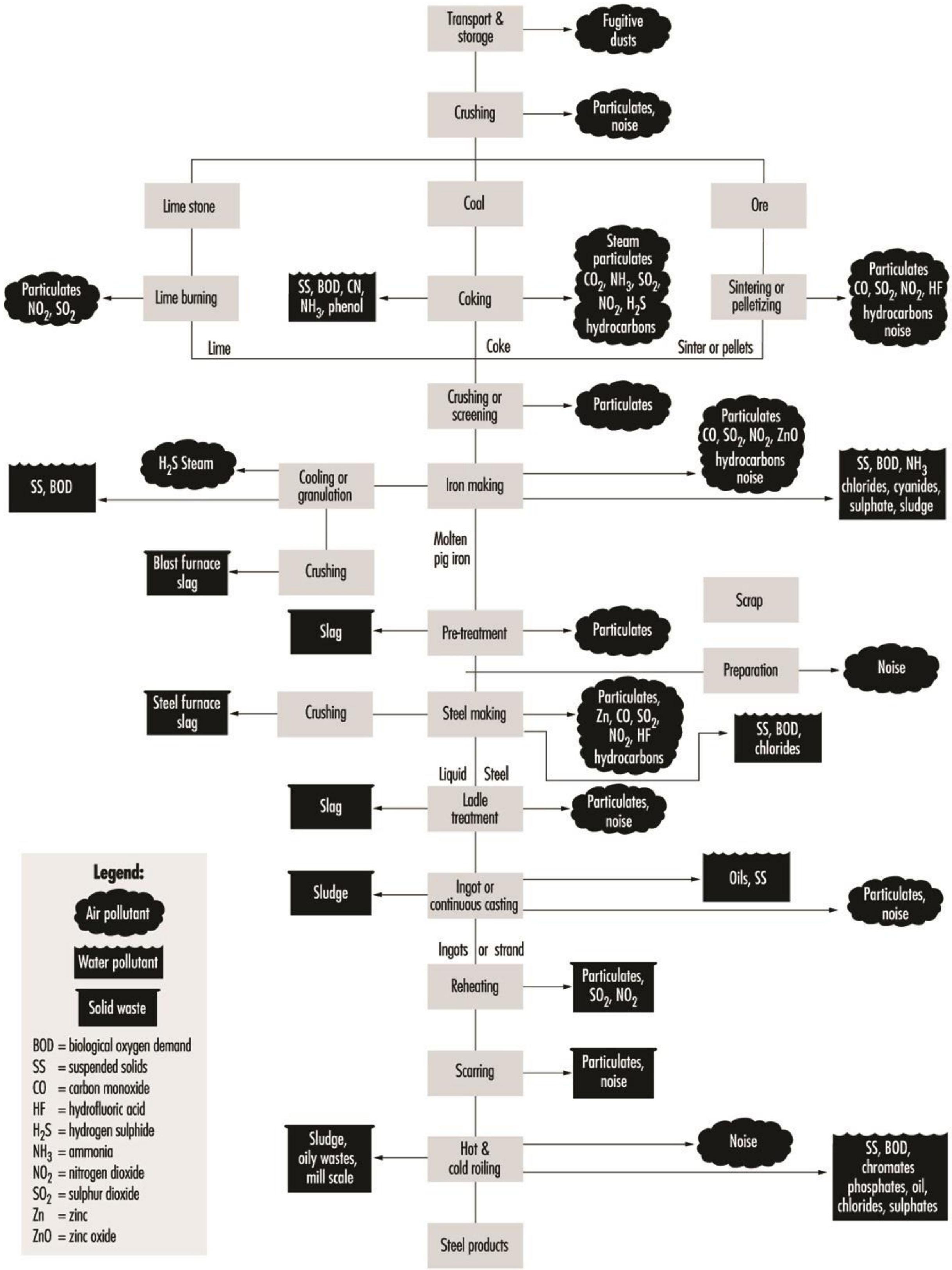


Fig: 1 Flow chart linking pollutants and principal operations in an integrated Steel plant

OBJECTIVES OF THE STUDY

The major objectives of this study were:

- Physico-chemical and mineralogical characterization of Solid wastes
- To assess the compatibility of industrial solid waste as raw material/ blending material/ mixture
- To examine the constraints related to utilization of Solid waste
- To make recommendations to promote utilization of Solid waste

CHAPTER – 2

LITERATURE REVIEW

Review of Literature

The rapid industrialization has resulted in generation of large quantities of wastes. Most of the wastes do not find any effective use and create environmental and ecological problems apart from occupying large tracts of valuable cultivable land. It has been observed that some of these wastes have high potential and can be gainfully utilized as raw mix / blending component in cement manufacturing.

The utilization of the industrial solid wastes in cement manufacture will not only help in solving the environmental pollution problems associated with the disposal of these wastes but also help in conservation of natural resources (such as limestone) which are fast depleting. The other benefits to cement industry include lower cost of cement production and lower greenhouse gas emission per tonne of cement production. This may also enable cement industries to take benefits of carbon trading.

Current production of steel slag is around 12 million tonnes per annum. However, with steel production on the rise, slag production is also expected to increase manifold. In contrast with other nations, most slag produced in India, especially steel slag, is discarded, however, this is increasingly becoming a problem due to paucity of land; utilization of slag is in the trial phase.

Nayak , P. N. and **Pal, B. K.** (2010) studied and discussed about characterisation of solid waste generated from Bhilai Steel Plant and described their physical , chemical and mineralogical properties by conducting different experiments. They also studied integrated approach of mineralogy, mineral chemistry, and elemental distribution pattern in waste and causative factors contributing to the problem precluding their optimal utilisation

Esezobor et al (1992) discussed about waste less Technology in Blast Furnace Operations and studied about different methods to separate useful materials from waste. He also studied the technology of recycling the wastes through sintering. The process includes sedimentation, thickening, classification and filtration with blending with dry wastes.

Aydin et al (2000) described method to reduce iron oxides in solid waste and summarized method to create sponge iron from these solid waste to reuse it. He also used different reducing agent to break the waste into useful substance as far as possible and studied kinetics of reduction process and correlated it with the Ginstling-Brounshtein model.

Das et al (1996) worked on different approach towards utilisation of solid wastes generated in steel plants and discussed creation of some products like products are wear resistant ceramic lining materials, ceramic floor refractory aggregate for high alumina cement cast able, & wall tiles, etc.

Bandopadhyay et al (2006) studied methodologies for the utilisation of wastes from metallurgical and allied industries. This methodologies were mostly based on smelting reduction of red mud to produce pig iron, mechanical activation of the slag and fly ash to prepare improved blended cements in terms of higher usage of waste and enhanced cement properties, synergistic usage of fly ash, blast furnace slag and iron ore tailings in the preparation of floor and wall tiles preparation of synthetic granite from fly ash as a value added product.

Sinha et al (1999) summarized the work done at various steel plants of the country in the area of utilization of waste which includes use of LD slag as soil conditioner, recycling of LD slag through sinter routes, manufacture of fly-ash bricks & light weight aggregates, agglomeration& recycling of lime fines.

Dykstra et al. (2000) attempted high resolution micro petrographic study of coarse-grained agglomerated MSN fly-ash. Hoffman (1998) discussed the use of fly-ash in Western United States. Kirk and Davis (1999) have determined the usefulness of fly-ash to control bacterial growth in diary bedding.

Vimal et al (1999) constructed the potential of returns in dollars following various utilization avenues of Indian fly-ash like fly-ash cement, fly-ash based wood substitute, and fly-ash based tiles, paints &enamels, reclamation of low lying areas, in the construction of road and fly over, embankments and so on. Nayak et al (1999) reported the preparation of fly-ash bricks, aggregates etc.

Problems in utilisation

One of the major factors hindering the utilization of industrial wastes has been an economic system for collection, handling and transportation of the wastes from the source plants and facilities for handling and storage at the user end. Most of the uses of industrial waste envisage collection of waste in dry state whereas system of disposal at most of the plants is wet, which has been established keeping in view the requirements of the existing systems and relatively easy mode of disposal. There is however, a possibility of dry collection of waste by incorporating modifications in the existing systems in most of the plants.

Blast furnace (BF) slag is a non-metallic by product produced during the process of iron making in a blast furnace. It consists primarily of silicates, alum inosilicates, and calcium alumina silicates. The molten slag usually absorbs most of the sulphur from the blast furnace charge.

Blast furnace slag is mildly alkaline and exhibits a pH in solution in the range of 8 to 10. Although blast furnace slag contains a small component of elemental sulphur (1 % to 2 %), the leachate tends to be slightly alkaline and does not present a corrosion risk to steels in pilings or to the reinforcement steels embedded in concrete structures made with blast furnace slag cement or aggregates.

Right now, there is no statutory regulation or norm for controlling the slag generation or for utilization of slag. However, sometime in 2003 the MoEF, came up with an innovative idea around steel slag – Corporate Responsibility on Environmental Production (CREP). The initiative aimed at waste minimization through 100% utilization of slag by recycling or reuse by 2008. However, the country has not been able to achieve this target due to the voluntary nature of the initiative and as well due to lack of interest by end-user segments.

Environmental impact of steel industry

Iron and steel industry which comprises, mining of ores, preparation of raw materials, agglomeration of fines in sinter plant, feeding of burden to blast furnace, manufacturing of coke in coke ovens, conversion of pig iron to steel, making and shaping of steel goods, granulation of slag for its use in cement plant, recovery of chemicals from Benzol and tar products etc. etc. All the above mentioned operations add to air, water, land and noise pollution

CHAPTER – 3

MATERIALS AND METHODS

Sample Detail

The samples of Blast furnace slag and steel making slag were collected from Rourkela Steel Plant.

- Blast Furnace Slag is formed when iron ore or iron pellets, coke and a flux (either limestone or dolomite) are melted together in a blast furnace. When the metallurgical smelting process is complete, the lime in the flux has been chemically combined with the aluminates and silicates of the ore and coke ash to form a non-metallic product called blast furnace slag. During the period of cooling and hardening from its molten state, BF slag can be cooled in several ways to form any of several types of BF slag products.
    1. **Granulated slag**: - Blast Furnace Slag is rapidly cooled by large quantities of water to produce a sand-like granule that is primarily ground into a cement commonly known as GGBS (Ground Granulated Blast Furnace Slag), or Type S slag cement. It is also mixed with Portland cement clinker to make a blended Type 1S cement
    2. **Air-cooled Slag**: - Blast furnace slag is allowed to slowly cool by ambient air, is processed through a screening and crushing plant and is processed into many sizes for use primarily as a construction aggregate. Common uses are as aggregates in ready-mix concrete, precast concrete, hot mix asphalt aggregate, septic drain fields and pipe backfill.
- **Steel making slag** is an unavoidable by-product in Iron & Steel making, it is essentially a mixture of metal oxides and silicon dioxide i.e. silicate. However, Iron & Steel Slag is non-metallic in nature and does not contain hazardous materials. Slag is an alternative construction material with superior environment friendly qualities and better product features.

Methodology

Ball Milling:-

It is a type of grinder, a cylindrical machine used for grinding and mixing of ores or raw materials. It rotates around a horizontal axis partially filled with material to be grind. Different material can be used for grinding media such as ceramic balls, Stainless steel balls. In laboratory it is used for grind ability index and work index.
Work index using following equation,

$$W_i = \frac{4{,}45}{P_1^{0{,}23} \times G^{0{,}82}\left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right)}$$

Where,
Pi is the aperture of the limiting screen (µm),
G is the net mass of screen undersize produced per mill revolution (g),
P is the d_{80}size of the mill product (µm), and
F is the d_{80} size of the mill feed (µm).

Procedure:

- A sample of slag is taken of weight 2 kg.
- It is crushed using crusher
- Now, sample is kept is cleaned ball mill cylinder to grind.
- Steel ball is used for grinding media.
- Ball mill is allowed to run for 40 minutes.
- After stopping machine steel balls are cleaned with brush.
- The mill was emptied and the ball mill charge was screened out.
- The grinded materials were screened on the sieves.

The main objective of ball milling is to grind the slag sample for further mineralogical, chemical and physical analysis.

Sieving Procedure:

Sieving is done for separating the products after grinding. It is a series of sieve arranged according to their mesh size. Vibrating sieve shaker is used for sieving

- The product we got from ball mill is kept on the topmost sieve and the whole arrangement is kept on vibrating sieve shaker.
- Machine is allowed to run for 7 to 10 minutes.
- Product size of -212 micron is collected at the bottom pan.
- Sample from pan is taken for further analysis

Pallet formation:

Changing or giving a shape to fine powder by applying high pressure. For this a small handy equipment is used.

- 1gm of fine powdered slag is taken.
- Powdered slag is kept in between of two cylindrical iron platens
- Pressure of 10 kg/cm^2 is applied for 5 minutes.
- Pressure is released and sample in form of cylinder is taken out.

PH analysis:

Determination of pH plays an important role in the any utilisation process plan. According to their acidic and basic nature their utilisation is carried out. If the substance is found out to be acidic it is used in the places where alkalinity is more and vice versa. As slag is used as soil conditioner it is very important to know their nature.

Procedure

- 5gms of powered slag is taken.
- 20ml of water is used to dissolve slag powder
- Now water is filtered using filter paper
- Filtered water is left for 15 minutes.
- A litmus paper is dipped into water.
- Change in colour of litmus paper is compared with standard colour chart

Table: 2 Result of pH analysis

Sample	pH	Remark
Granulated slag	3.5	Basic
Air-cooled Slag	3.7	Basic
steel making slag	3.5	Basic

Basically Slag formed is treated with limestone to make it basic as it is acidic in nature as acidic slag is far more hazardous than alkaline slag.

Bulk Density:

Bulk density is a property of powders, granules, and other “divided” solids, especially used in reference to mineral components (soil, gravel), chemical substances, (pharmaceutical) ingredients, foodstuff, or any other masses of corpuscular or particulate matter. It is defined as the mass of many particles of the material divided by the total volume they occupy. The total volume includes particle volume, inter-particle void volume, and internal pore volume.

Bulk density is not an intrinsic property of a material, it can change depending on how the material is handled.

Procedure:

- Slag sample size of 25 – 50mm is taken
- A container of known volume is taken.
- Sample is completely filled in container till top

Bulk Density = (wt. of the sample) / Volume of container

Bulk Density of Air cooled slag:

Weight of the sample taken = 500g
Volume of the container = 250ml
Hence, Bulk Density is 2 gm. /ml

Bulk Density of Granulated slag:

Weight of the sample taken = 934g
Volume of the container = 250ml
Hence, Bulk Density is 3.76 gm. /ml

Bulk Density of SMS slag:

Weight of the sample taken = 873 g
Volume of the container = 250ml
Hence, Bulk Density is 3.51 gm. /ml

Table: 3 Result of Bulk Density of Slag

Sample	Bulk Density
Granulated slag	3.76
Air-cooled Slag	2
steel making slag	3.51

Los Angeles Test:

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics.

- Aggregate used in highway pavement should be hard and must resist wear due to the loading from compaction equipment, the polishing effect of traffic and the internal abrasion effect.
- The road aggregate should be hard enough to resist the abrasion of aggregate. Resistance to abrasion is determined in laboratory by loss angles abrasion test.

Principle of test:
To produce the abrasive action by use of standard steel balls which when mixed with the aggregate and rotated in a drum for specific number of revolution cause impact on aggregate. The %age wear due to rubbing with steel balls is determined and is known as abrasion value.

The test helps to find the degradation of mineral aggregates when subjected to abrasion, impact, or grinding.

Procedure
- Sample of size 2mm is taken.
- Steel ball is used as grinding media is kept in machine with sample.
- Machine is rotated for 500 revolution at 32rpm.
- Sample is collected in sieve of 2mm

$$\%loss = \frac{Difference\ in\ weight}{Original\ Weight} * 100$$

Result
For air cooled slag:-

Original Weight taken = 1 kg
Weight retrieved = 616.36 gm
Weight loss = 383.64 gm

$$\%\ loss = \frac{383.64}{1000} * 100$$

$$= 38.36\ \%$$

For Granulated slag:-

Original Weight taken = 1 kg
Weight retrieved = 452.04 gm
Weight loss = 547.96 gm

$$\%\ loss = \frac{547.96}{1000} * 100$$

$$= 54.79\ \%$$

For SMS slag:-

Original Weight taken = 1 kg
Weight retrieved = 475.62 gm
Weight loss = 524.38 gm

% loss = $\frac{524.38}{1000} * 100$

= 52.43 %

Table: 4 Result of Los Angeles Test

Sample	% loss due to Abrasion
Air Cooled Slag	38.36
Granulated Slag	54.79
SMS Slag	52.43

Porosity Analysis:

Porosity is a measure of how much of a rock is open space. This space can be between grains or within cracks or cavities of the rock. Permeability is a measure of the ease with which a fluid (water in this case) can move through a porous rock.

Procedure

- Initial weight of sample is noted down.
- Sample of 100gm is taken and dipped into water completely.
- Slag is allowed to be in 350ml water for 1 day.
- Volume of sample is find out by volume of water displaced.
- Final weight of sample is noted down.

Porosity is calculated by following equation:-

$$\text{Porosity} = \frac{Volume\ of\ water\ absorbed}{Volume\ of\ Slag}$$

Result

Air Cooled Slag:

Volume of Water taken = 350 ml
Volume of water after dipping sample = 372 ml

So, Volume of sample = 22 ml
Water absorbed by sample = 11.45 ml
Porosity = 52 %

Granulated Slag:

Volume of Water taken = 350 ml
Volume of water after dipping sample = 367ml

So, Volume of sample = 17 ml
Water absorbed by sample = 0.289 ml
Porosity = 1.7 %

SMS Slag:

Volume of Water taken = 350 ml
Volume of water after dipping sample = 363 ml

So, Volume of sample = 13 ml
Water absorbed by sample = 23.4 ml
Porosity = 1.8 %

Table: 5 Result of Porosity Analysis

Sample	% porosity
Air Cooled Slag	52
Granulated Slag	1.7
SMS Slag	1.8

Size Analysis:

- Slag sample was taken by crushing it using a jaw crusher.
- Sample is sieved using sieve shaker of sieve size 1000µ , 500µ , 250µ, 125µ, 75µ , 37µ , <37µ
- Each of the sieve product was weighted.
- Now, sample is kept is cleaned ball mill cylinder
- After that, the mill was emptied and the ball mill charge was screened out.
- The grinded materials were screened on the sieves.
- Sieving is done for 7 – 10 minutes
- Sieved samples are weighted again

Table: 6 Size Analysis for SMS Slag:

Size (µ)	Weight	Weight (%)	Cumulative Weight
1000	56.67	14.22	14.22
500	134.23	33.70	47.92
250	115.26	28.94	76.86
125	26.03	6.53	83.39
75	24.04	6.03	89.42
37	19.01	4.77	94.19
<37	23.02	5.78	99.97

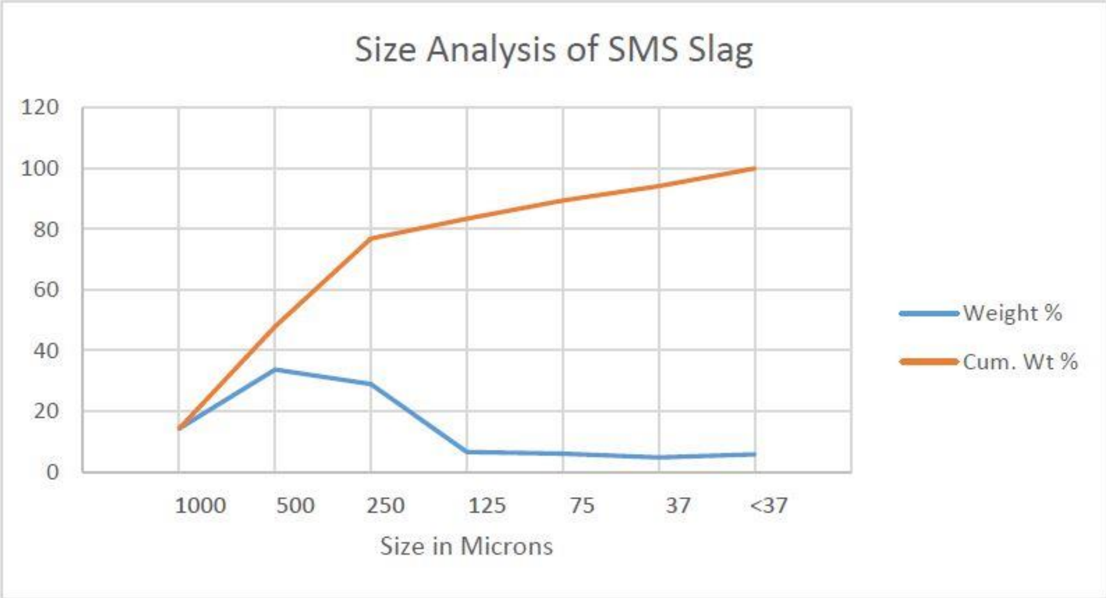


Fig: 2 Size Analysis of SMS Slag

Table: 7 Size Analysis for Granulated Slag

Size (µ)	Weight	Weight (%)	Cumulative Weight
1000	73.24	19.33	19.33
500	123.11	32.50	51.83
250	98.26	25.94	77.77
125	27.26	7.22	84.99
75	31.23	8.24	93.23
37	11.54	3.04	96.27
<37	14.01	3.69	99.96

Fig: 3 Size Analysis of Granulated Slag

Table: 8 Size Analysis for Air Cooled Slag

Size (µ)	Weight	Weight (%)	Cumulative Weight
1000	68.99	17.84	17.84
500	129.84	33.59	51.43
250	120.19	31.09	82.52
125	21.46	5.55	88.07
75	20.02	5.18	93.25
37	11.02	2.85	96.10
<37	15.00	3.88	99.98

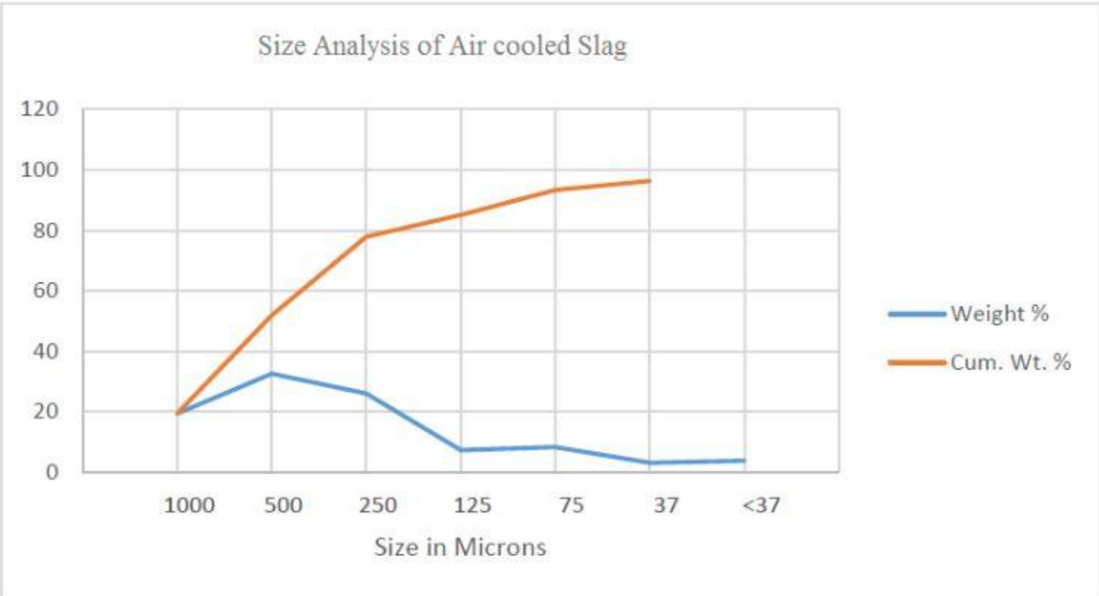


Fig: 4 Size Analysis of Air Cooled Slag

Scanning Electron Microscopy:

Scanning Electron Microscopy (SEM), also known as SEM analysis or SEM microscopy, is used very effectively in microanalysis and failure analysis of solid materials. Scanning electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects. Intertek scanning electron microscopy scientists analyse the surface of solid objects, producing higher resolution images than optical microscopy. SEM produces representations of three-dimensional samples from a diverse range of materials. Back-scatter and cathodoluminescence (SEM-CL) are used to evaluate a wide range of samples.

Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX) is the best known and most widely-used of the surface analytical techniques. High resolution images of surface topography, with excellent depth of field, are produced using a highly-focused, scanning (primary) electron beam. The primary electrons enter a surface with an energy of 0.5 – 30 kV and generate many low energy secondary electrons. The intensity of these secondary electrons is largely governed by the surface topography of the sample. An image of the sample surface can thus be constructed by measuring secondary electron intensity as a function of the position of the scanning primary electron beam. High spatial resolution is possible because the primary electron beam can be focused to a very small spot (<10 nm). High sensitivity to topographic features on the outermost surface (< 5 nm) is achieved when using a primary electron beam with an energy of < 1 kV. An Energy Dispersive X-Ray Analyser (EDX or EDA) is also used to provide elemental identification and quantitative compositional information. SEM provides images with magnifications up to ~X20, 000 allowing sub-micron scale features to be seen i.e. well beyond the range of optical microscopes.

- Rapid, high resolution imaging with identification of elements present
- Spatially resolved quantitative EDX (EDA) analysis of user defined areas on sample surface
- Characterisation of particulates and defects
- Examination of grain structure and segregation effects
- Coating thickness measurement using cross sectional imaging of polished sections.

Applications

- Characterisation of material structures
- Assessment of reaction interfaces, service environment and degradation mechanisms
- Characterisation of surface defects, stains and residues on metals, glasses, ceramics and polymers
- Measurement of the thickness of layered structures, metallised layers, oxide films, composite materials using cross sectional imaging
- Particulate and contaminant analysis on and within materials.

SEM of Air Cooled slag:

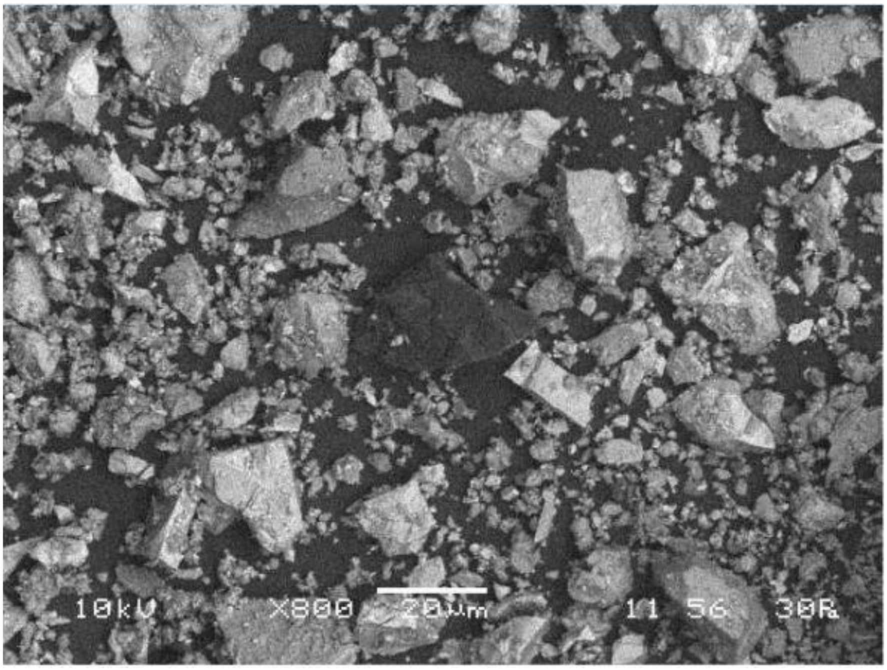


Fig: 5 SEM done at magnification of 250 showing Calcium oxide and silicate

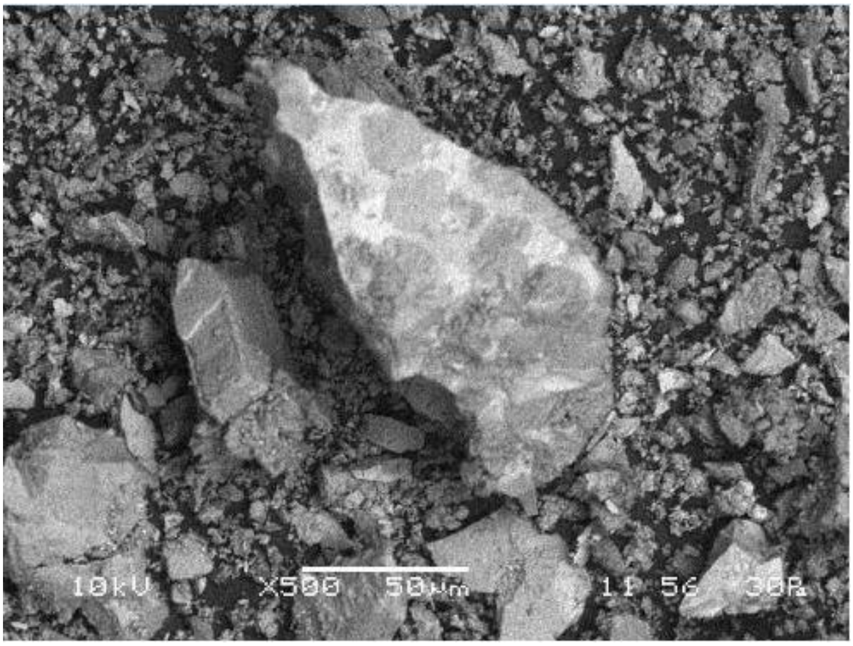


Fig: 6 SEM done at magnification of 500 showing presence of quartz and lime

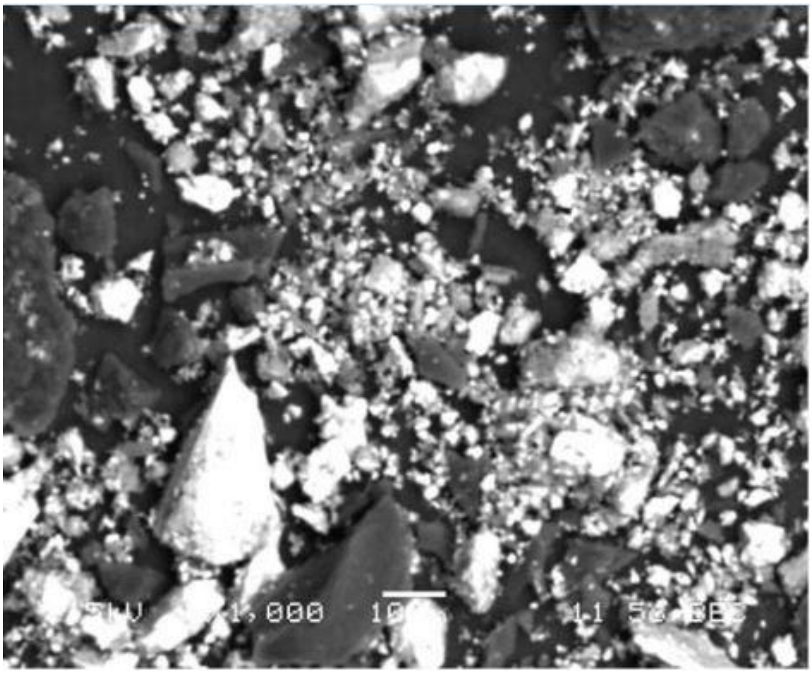


Fig: 7 SEM done at magnification of 1000 representing presence
Of particles of quartz, lime with dolomite

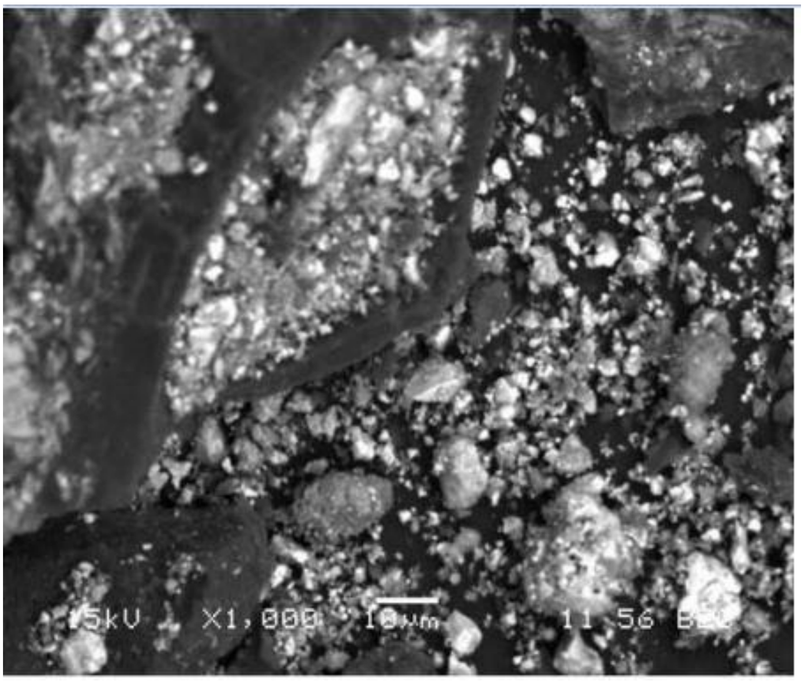


Fig: 8 SEM done at magnification of 1000 representing presence of particles of quartz, magnetite and Lime

SEM of granulated slag:

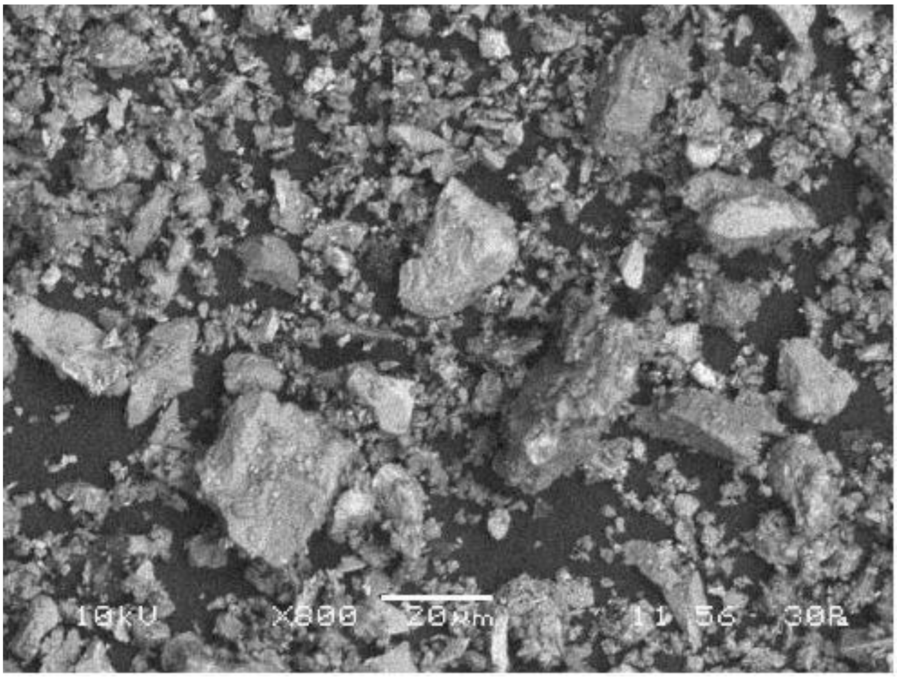


Fig: 9 SEM done at magnification of 250 representing Mixture of Quartz, Dolomite, Hematite

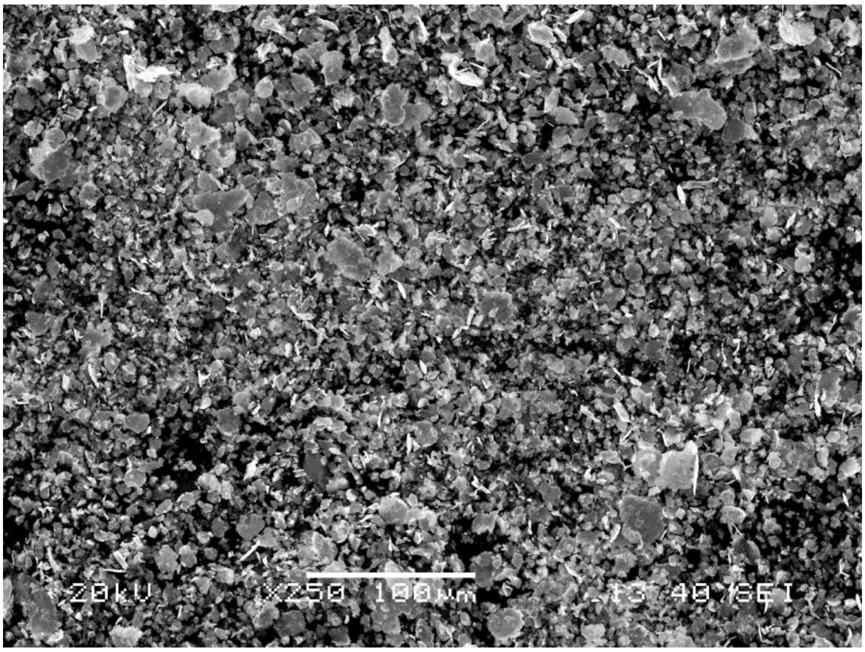


Fig: 10 SEM done at magnification of 250 representing mixture of Lime, Dolomite , Quartz

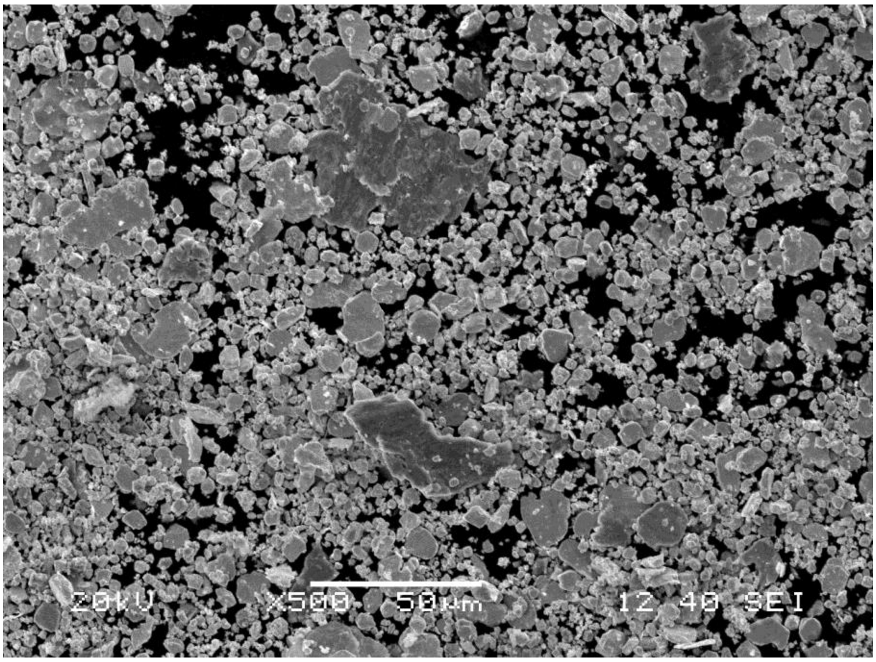


Fig: 11 SEM done at magnification of 500 representing Quartz in dominant

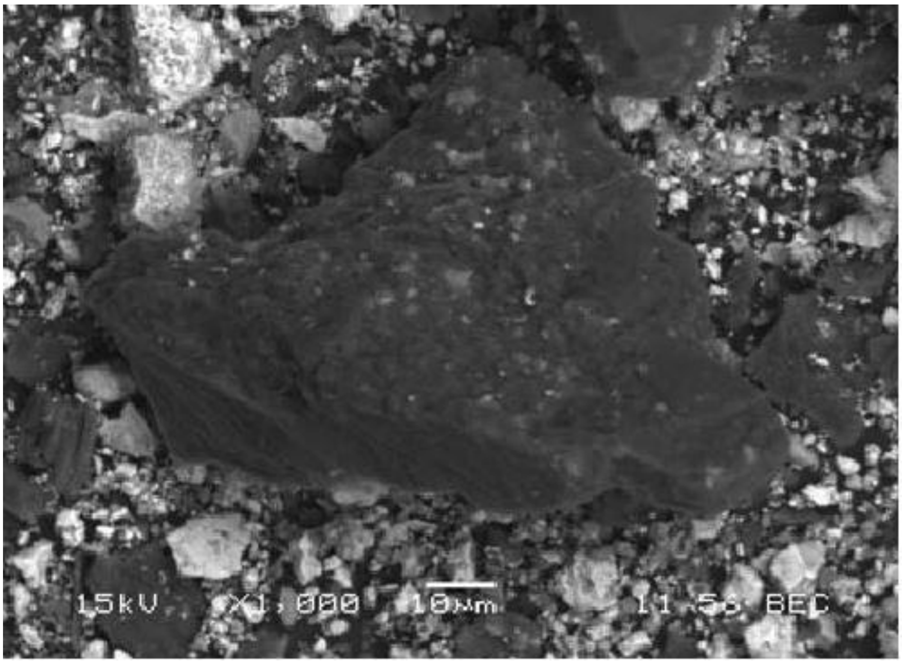


Fig: 12 SEM done at magnification of 1000 representing Alumina oxide in dominant

SEM of SMS Slag:-

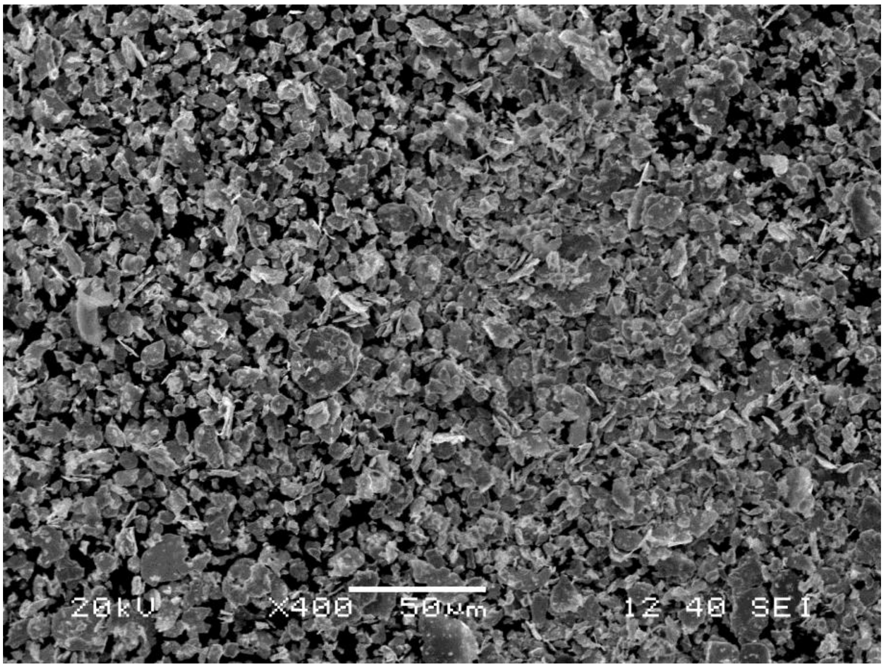


Fig: 13 SEM done at magnification of 400 representing mixture of Quartz, Hematite
Wustite, And Magnetite

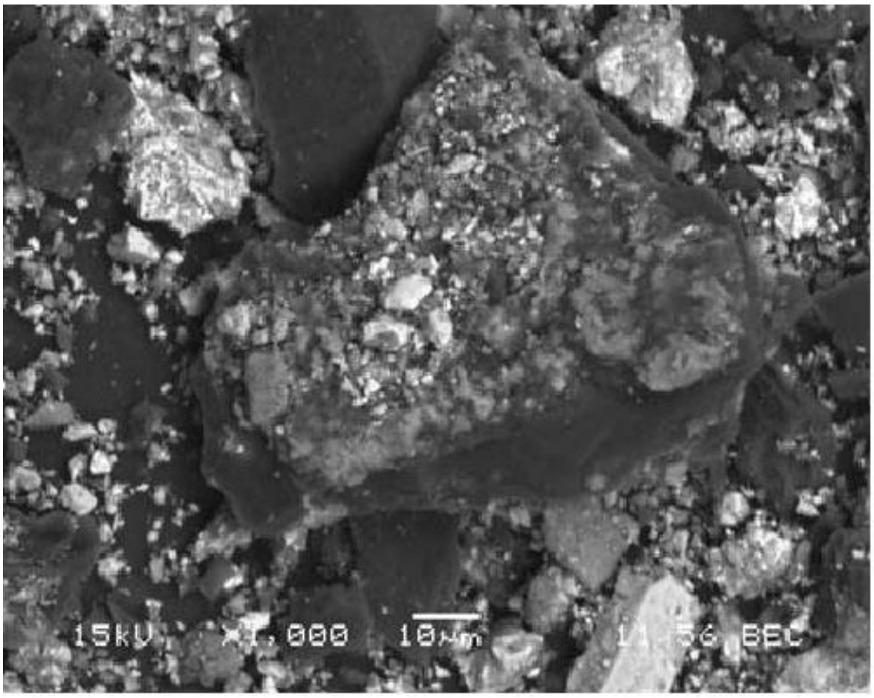


Fig: 14 SEM done at magnification of 100 representing mixture
Of Hematite with Quartz

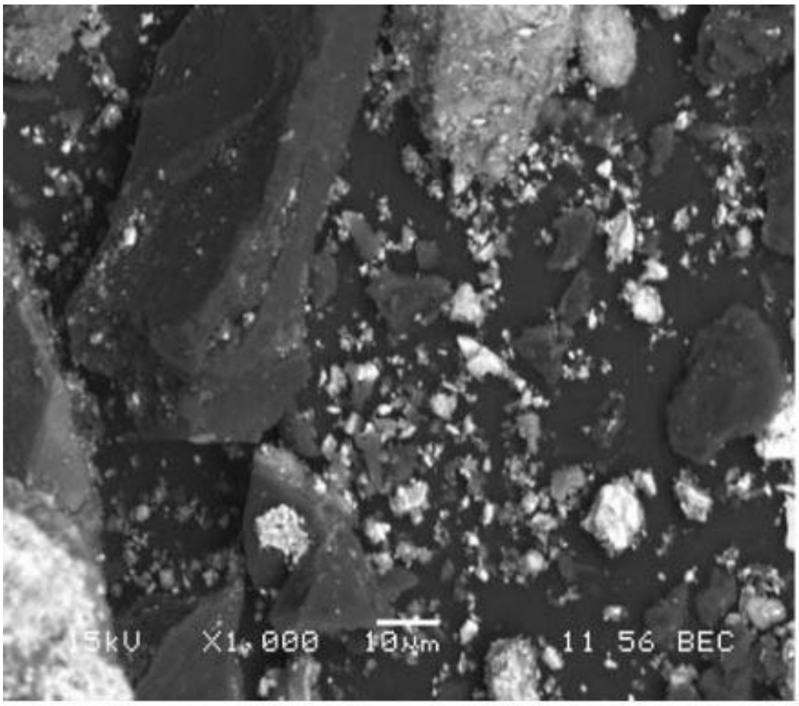


Fig: 15 SEM done at magnification of 1000 representing mixture of Hematite,
Quartz with Magnetite

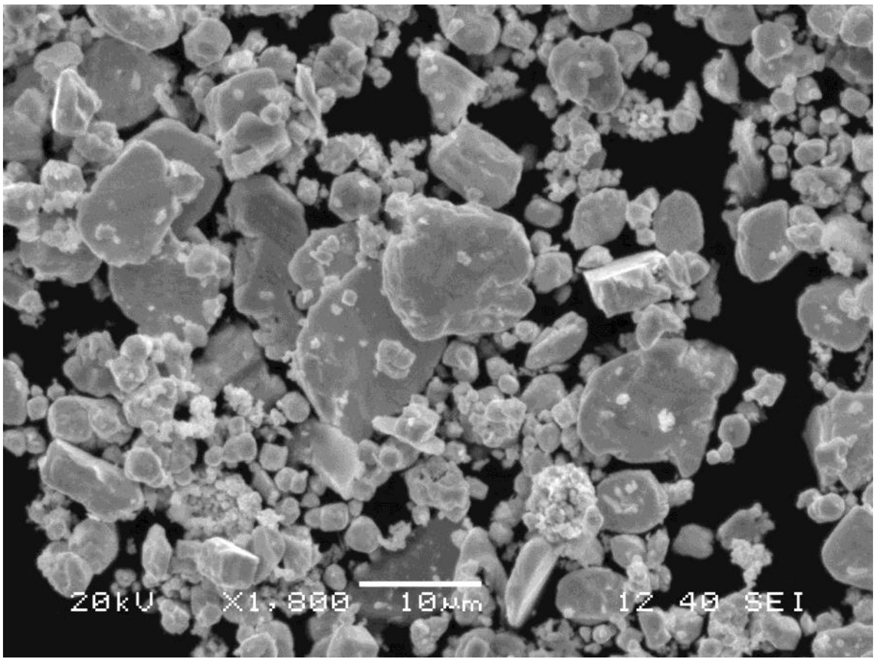
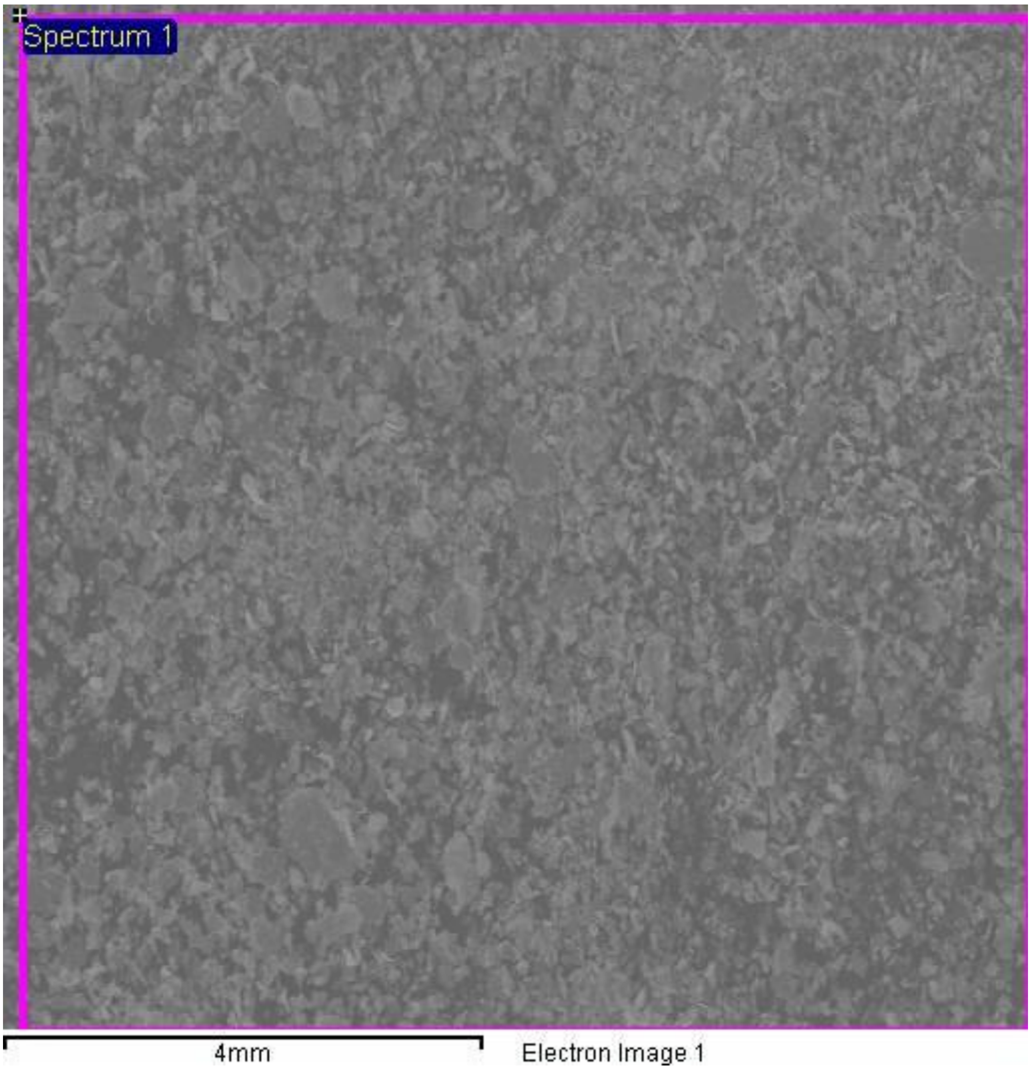


Fig: 16 SEM done at magnification of 1000 representing clear crystal of Quartz



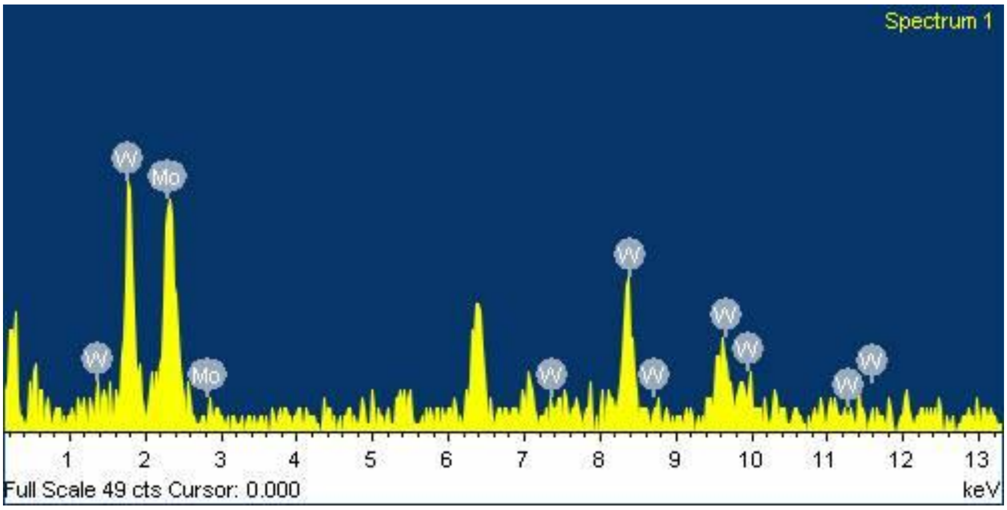
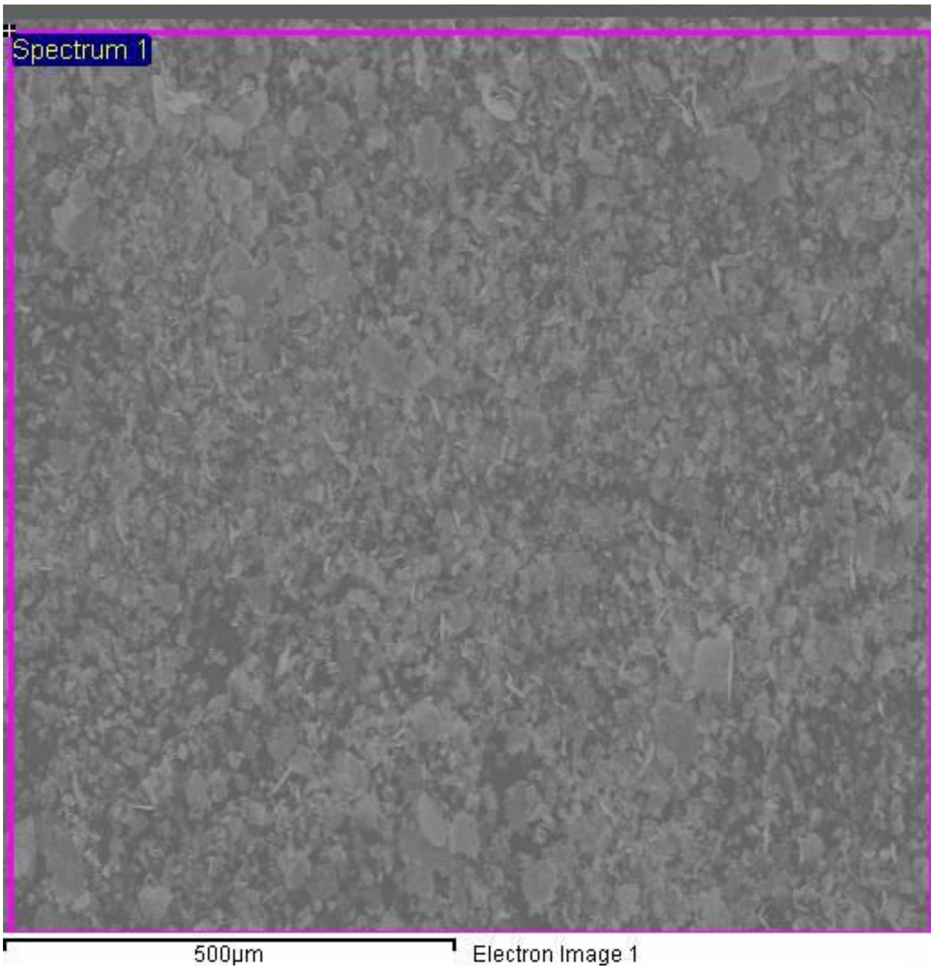


Fig: 17 Energy dispersive X-ray spectroscopy of granulated slag representing presence of Wustite and Mullite



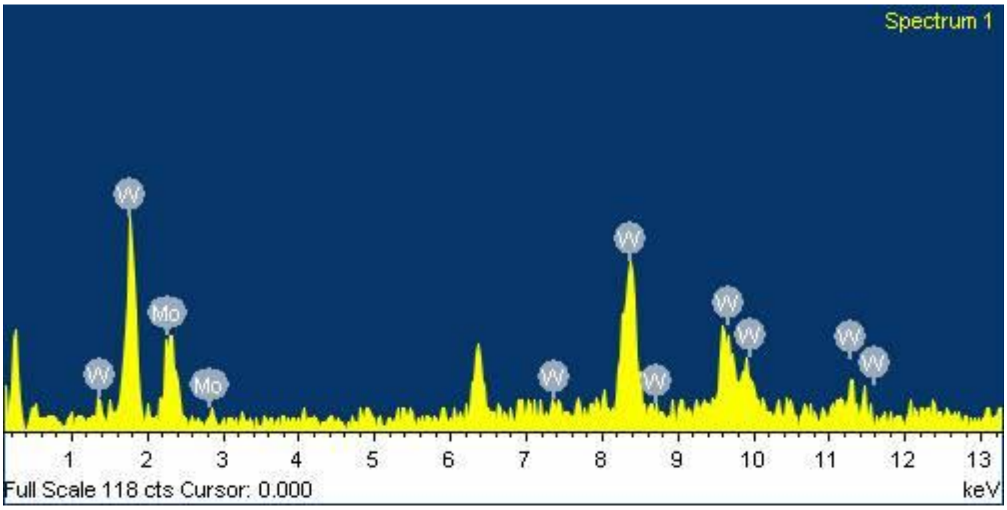


Fig: 18 Energy dispersive X-ray spectroscopy of air cooled slag representing dominant presence of Wustite

X-ray diffraction:

X-ray diffraction (XRD) is a powerful non-destructive technique for characterizing crystalline materials. It provides information on structures, phases, preferred crystal orientations (texture), and other structural parameters, such as average grain size, crystallinity, strain, and crystal defects. X-ray diffraction peaks are X-ray Diffraction (XRD) and X-ray Reflectivity (XRR) techniques from Evans Analytical Group (EAG).produced by constructive interference of a monochromatic beam of x-rays scattered at specific angles from each set of lattice planes in a sample. The peak intensities are determined by the distribution of atoms within the lattice. Consequently, the x-ray diffraction pattern is the fingerprint of periodic atomic arrangements in a given material. A search of the ICDD standard database of x-ray diffraction patterns enables quick phase identification for a large variety of crystalline samples.

Instrument and measuring principle

XRD analysis is based on constructive interference of monochromatic X-rays and a crystalline sample: The X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample.

The characteristic x-ray diffraction pattern generated in a typical XRD analysis provides a unique "fingerprint" of the crystals present in the sample. When properly interpreted, by comparison with standard reference patterns and measurements, this fingerprint allows identification of the crystalline form.

XRD of Air cooled slag:-

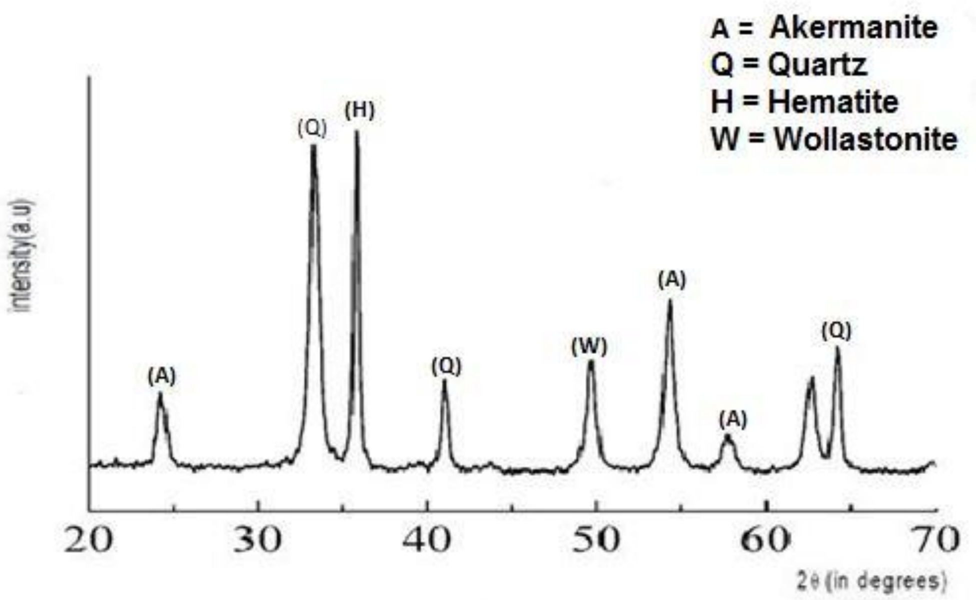


Fig: 19 XRD of Air cooled slag

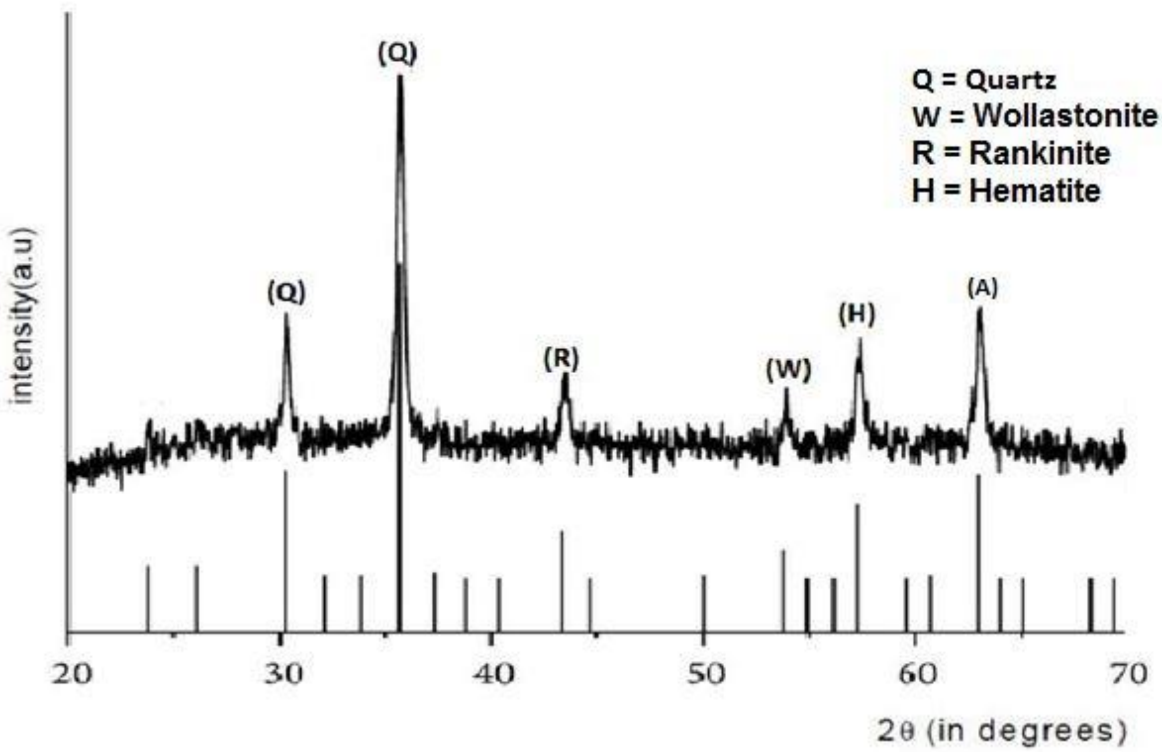


Fig: 20 XRD of Air cooled slag

XRD of Granulated slag:

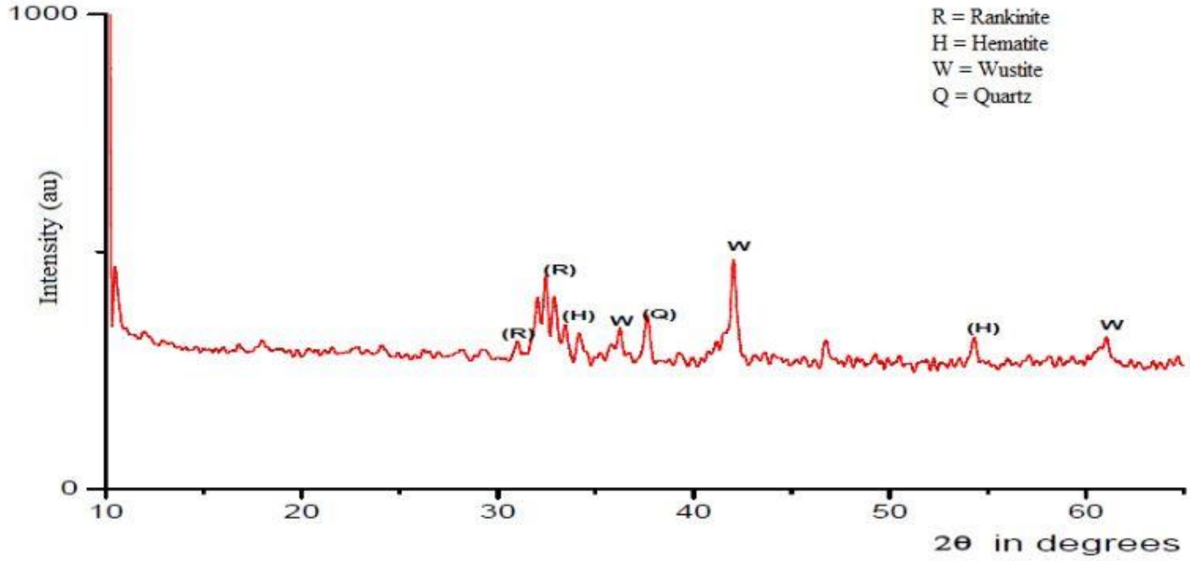


Fig: 21 XRD of Granulated slag

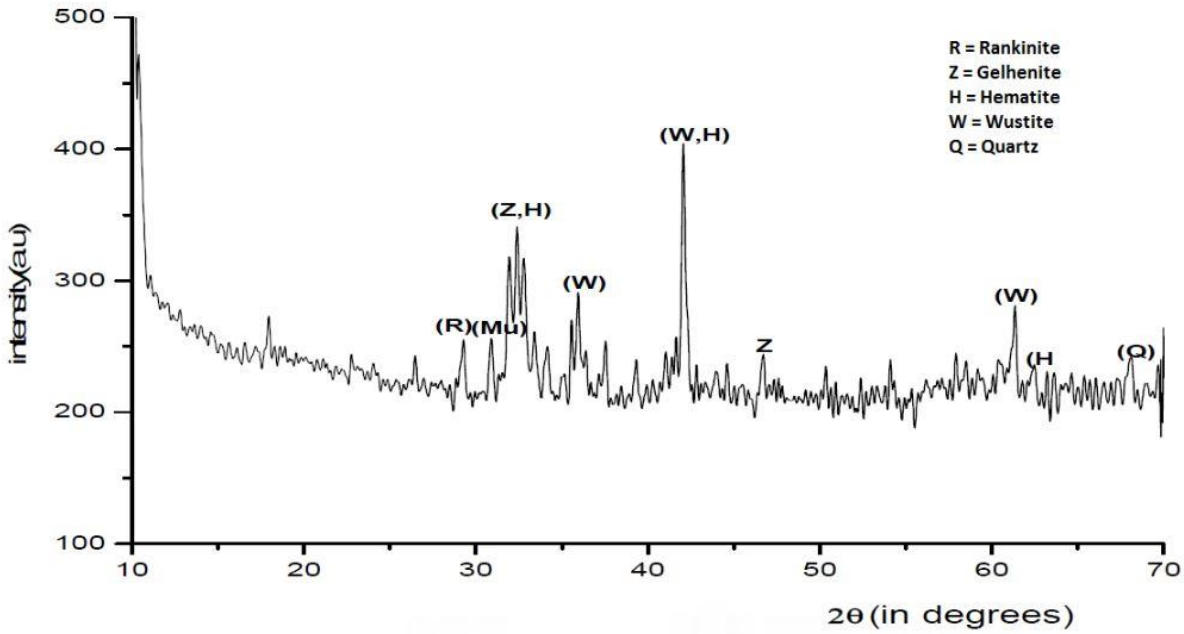


Fig: 22 XRD of Granulated slag

XRD of SMS Slag:

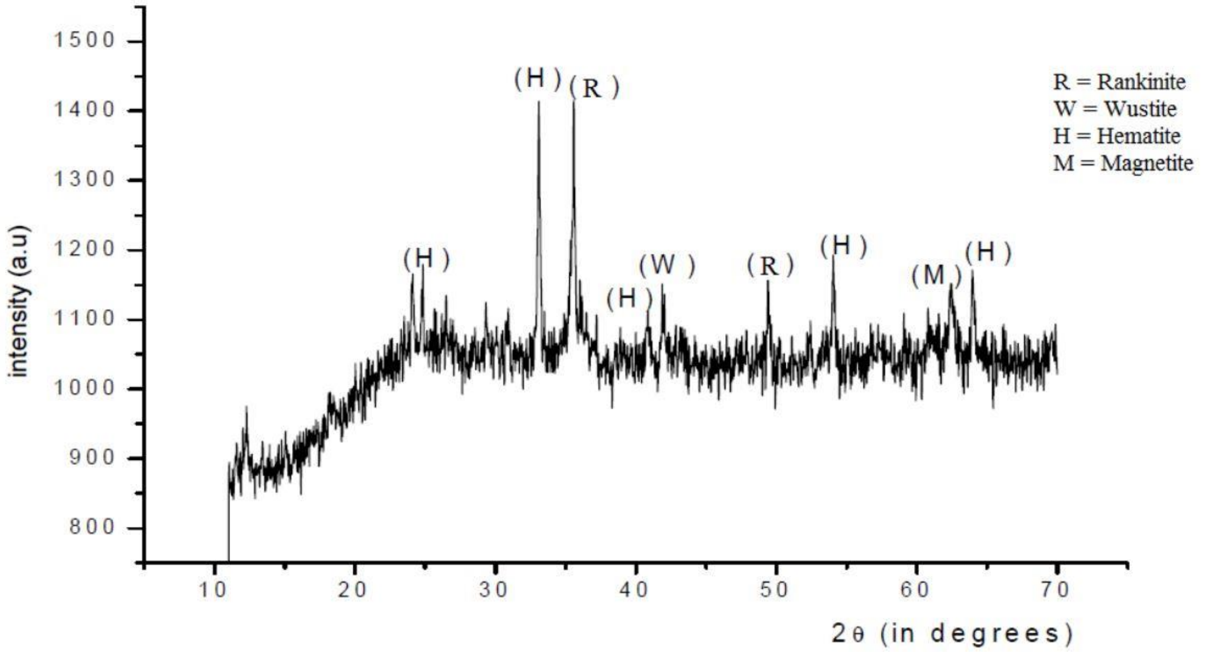


Fig: 23 XRD of SMS Slag

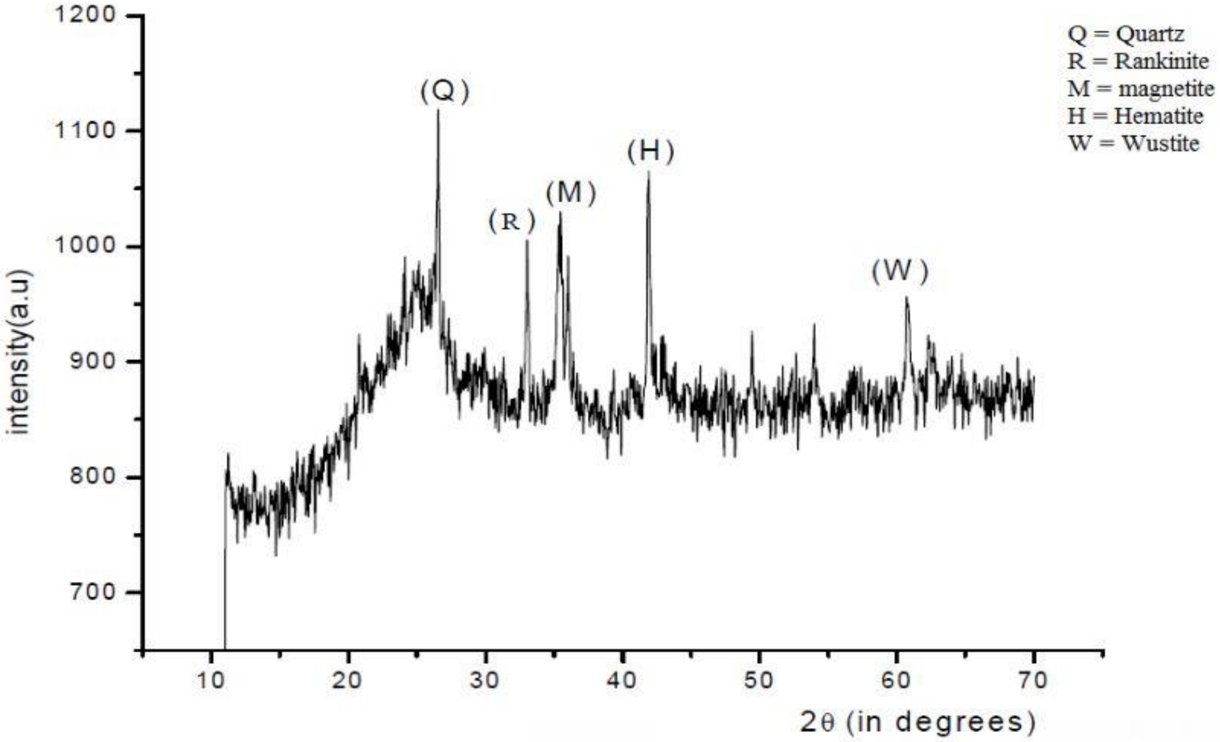


Fig: 24 XRD of SMS Slag

CHAPTER – 4

RESULT AND DISCUSSION

RESULT

Slags from the iron and steel industries are sometimes erroneously classified, an often looked upon, as industrial waste materials. In actual fact, these by-products are valuable and extremely versatile construction materials. In relatively recent years, the need for maximum utilization and recycling of by-products and recovered waste materials for economic and environmental reasons has led to rapid development of slag utilization. In some areas, nearly all of the iron and steel slags are now being used, and use is rapidly growing in many others.

Physical properties

Table: 9 Physical properties of Slag

Properties	Air Cooled Slag	Granulated slag	Steel Making Slag
Porosity	52	1.7	1.8
Los Angles	38.36	54.79	52.43
Bulk Density	2	3.76	3.51

Mineralogical Properties

Table: 10 Mineralogical Properties of slag

Slag	Presence of Mineral
Air Cooled Slag	• Rankinite ($Ca_3OSi_2O_7$) • Wollastonite ($CaOSiO_2$) • Quartz (SiO_2) • Akermanite ($CaOMgOSi_2O_4$)
Granulated slag	• Rankinite ($Ca_3OSi_2O_7$) • Wustite (FeO) • Quartz (SiO_2) • Hematite (Fe_2O_3)
Steel Making Slag	• Rankinite ($Ca_3OSi_2O_7$) • Wustite (FeO) • Quartz (SiO_2) • Hematite (Fe_2O_3) • Magnetite (Fe_3O_4)

Chemical Properties:

Chemical analyses of blast-furnace slags usually show that the four major oxides (lime, magnesia, silica and alumina) make up about 95% of the total. Minor elements include sulfur, iron, manganese, alkalis, and trace amounts of several others.

Table: 11 pH analysis

Properties	Air Cooled Slag	Granulated slag	Steel Making Slag
pH	3.7	3.5	3.5

Table: 12 Result shown by Scanning Electron Microscope

Slag	Chemical Composition (Weight Percent)
Air Cooled Slag	• CaO (28 - 45) • SiO_2 (30 - 42) • Al_2O_3 (6 - 12) • MgO (5 - 9)
Granulated slag	• CaO (30 - 42) • SiO_2 (25 - 38) • Al_2O_3 (4 - 10) • MgO (8 - 14) • S (1 – 2)
Steel Making Slag	• $CaSi_2O_4$ (35 - 47) • $Ca_2(Al,Fe)_2O_5$ (29 - 48) • CaO (14 – 25) • SiO_2 (18 - 24) • Fe_2O_3 (2 - 5) • Fe_3O_4 (2 - 5)

The chemical composition of the slag is dependent upon the composition of the available iron ores, flux stones, and fuels, and on the proportions required for efficient furnace operations. The blast furnace must be charged with uniform raw materials if the iron produced is to be consistent in quality. This procedure also insures uniformity in the composition of the slag, and as a result the composition of slag from a given source varies within relatively narrow limits. Greater variations, as shown in the overall ranges above, may be found between sources where different raw materials are being used.

CHAPTER – 5

UTILIZATION OF WASTE

Utilisation

The air-cooled slag crushes to angular, roughly cubical particles with pitted surfaces. Excellent bond is provided with either hydraulic cements or bituminous binder materials. High internal friction values and particle interlock provide excellent stability when used without cements. Bulk specific gravity and unit weight are dependent upon grading and particle size; the larger particles contain more internal cells and have a lower bulk density. The coarse sizes may have bulk densities as much as 20% lower than natural aggregates with the same gradation, while the fine material (passing a4.75mm sieve) is nearly equal to natural sand in density. The aggregate is highly resistant to weathering effects, and does not readily polish to produce slippery surfaces.

The air-cooled slag coarse aggregates are usually classified with crushed stones and gravels as "normal weight" aggregates. They are used for all types of construction applications, just as the natural aggregates are; however, the weight saving in the case of slag becomes a significant factor in some applications.

The granulated slag glass contains the same major oxides as does cement, but with considerably different proportions of lime and silica. Like cement, it has excellent hydraulic properties and, with a suitable activator (such as calcium hydroxide) will set in a similar manner. Granulated slags may be crushed, graded or ground for specific applications.

Steelmaking slags are composed principally of calcium silicates, calcium aluminoferrites, and fused oxides of calcium, iron, magnesium, and manganese. The compositions vary with type of furnace, composition of furnace charges, grades of steel produced, and with individual furnace operating practices. Materials added to the melt just before the end of a heat may not be completely incorporated in the slag. Therefore, some free oxides, including CaO, may be found in some slags. Compared to blast-furnace slags, the steelmaking slags usually contain much higher amounts of iron and manganese, are lower in silica and may be higher in lime producing a much higher lime-silica ratio, and sulphur contents are usually quite low. Physically, the steelmaking slags are much heavier, harder, denser and less vesicular in nature, and have unusually high resistance to polishing and wear.

Table: 13 Study of Indian Standards for Slag

	Composition	Utilisation
Blast Furnace Slag	• CaO = 31 - 33 % • SiO_2 = 30 – 33 % • Al_2O_3 = 22 – 24 % • MgO = 9 – 12 %	• Slag Cement • Insulating Material • Building Roads
Steel Making Slag	• CaO = 43 -50 % • SiO_2 = 13 – 16 % • MgO = 5 – 8 % • MnO = 3 – 5 % • P_2O_5 = 2 – 3 % • FeO = 16 – 20 %	• Soil Conditioner for acidic soil • Source of flux in blast Furnace

Other application of slags:

- Usage of steel slag instead of natural aggregates avoids the environmental footprint of quarrying, and also prevents deforestation
- Steel slag makes roads safer to drive on by offering better skid-resistance and improves safety when used in the asphalt layer. The use of steel slag also provides economies of scale when used in the road construction process, addressing India's growing infrastructure needs
- Steel slag can be used as a soil neutralizer for highly acidic soils in areas such as Eastern India; it's use as a fertilizer has also been well-established
- Steel slag has a longer life and durability than natural aggregates when used as rail ballast, thus helping save maintenance costs
- Steel slag is being extensively used in landfills across the world, and is a viable alternative for use in India

CHAPTER - 6

CONCLUSION

Conclusion

Steelmaking slag is a bye-product of the steelmaking process. Nevertheless, it has been described so far, almost all steelmaking slag that produced is effectively utilized as a material for road base course material in road construction and other civil engineering projects, calcium-oxide-based reformer (for ground improvement, soil improvement), and raw materials for cement, fertilizer because of its mechanical properties and functions. Many of these uses represent natural substitutes for man-made material. We consider that the expansion of the applications of slag is an activity that greatly contributes to environmental conservation. In future, we wish to further contribute to our society by pressing ahead with the development of new functions for steelmaking slag and further expanding its application.

Air Cooled Slag can be used at many and different places, including all types of construction aggregate applications in addition to manufacture of mineral wool, cement and glass and as a soil conditioner.

Granulated blast-furnace slag production is quite small and can be mainly used in road base and fill construction as they are hard and have high compressive strength.

Steelmaking slags are can be used as

- Source of iron and flux materials in blast furnaces
- High quality mineral aggregate for specific uses where skid-resistant properties are required.

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